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Analysis of engine piston and piston ring using CATIA and ANSYS for attaining higher Efficiency

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ABSTRACT
In this present work a piston and piston ring are designed for a single cylinder four stroke petrolengineusingCATIAV5R20software. Complete design is imported to ANSYS14.5 software and then analysis is performed. Three different materials have been selected for structural and thermal analysis of piston. For piston ring two different materials are selected and structural and thermal analysis is performed using ANSYS14.5software. Results are shown and a comparison is made to find the most suited design.

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I. Introduction

The modern trend is to develop IC Engine of increased power capacity. One of the design criteria is the endeavor to reduce the structures weight and thus to reduce fuel consumption. This has been made possible by improvedenginedesign.Theseimprovementsincludeincreaseduseoflight- weight materials, such as advanced ultra-high tensile strength steels, aluminum and magnesium alloys, polymers, and carbon-fiber reinforced composite materials. The integration of lighter weight materialsisespeciallyimportantifmorecomplexpartscanbemanufacturedasasingleunit.Inthe next 10–20 years, anadditional 20–40% reduction inoverall weight, without sacrificing safety, seemstobepossible.Cuddyetal (1997)havereportedthatforevery10%weightreductionofthe vehicle,animprovementin fuelconsumptionof6–8%is expected.Improvedenginedesignrequires optimized engine components. Therefore sophisticated tools are needed to analyze engine components.Enginepistonisoneof themostanalyzedcomponentsamongallautomotiveor other industryfieldcomponents.Theenginecanbecalledtheheartofanautomobileandthepistonmaybe considered themost importantpartofanengine. Many sophisticated Aluminumpistonanalysis methods have beenreported inthepastyears. Silva2006hasanalyzed fatiguedamagedpiston. Damagesinitiatedat the crown,ringgrooves,pinholesandskirtare assessed.An analysisofboth thermalfatigueandmechanicalfatiguedamagesispresentedandanalyzedinthiswork.Alinear staticstressanalysis,using''cosmosworks'',is usedtodeterminethestressdistributionduringthe combustion.Stressesatthepistoncrownandpinholes,aswellasstressesatthegroovesandskirtas a function oflandclearancesarealsopresented. Buyukkaya et al (2007) hasinvestigatedaconventional(uncoated)dieselpiston,madeofaluminumsiliconalloyandsteel.Hehas performed thermalanalysesonpistons,coatedwith$MgO–ZrO_2$ materialbymeansofusingacommercialcode, namelyANSYS. Finally,theresultsoffourdifferentpistonsarecompared witheachother.The effectsof coatingsonthethermalbehaviorsofthepistonsareinvestigated.Ithasbeenshownthatthe maximumsurfacetemperatureofthecoatedpistonwithmaterialwhichhaslowthermalconductivity isimprovedapproximately48%fortheAlSialloyand35%forthesteel.Saadetal.(2008) has donenumericalanalysis toanalyzethestressesduetothermalcyclewithdifferentaluminumalloy ofpiston.Finiteelementmethodwasusedtoevaluatethecouplingfield(thermal–stress)onthe piston.ANSYS5.4Finiteelementcodeisusedto carryoutthemodelingprocesstodeterminethe couplingstress.Twomodelswiththreedimensions arecreated. The firstisused to evaluate the temperature distribution through the pistonvolume, and these co disused to evaluate the thermal stressdistributionduetoheatgradientanddifferentmaterials.Theresultshowthemaximumrange oftemperaturesis4.3°Candincreaseswithdecreasingofmaterialthermalconductivity.Thermal stressisconcentratedonthepistonedges and depends on the material types. Gudimetaletal. (2009) hasreported a CADmodelofadamagedinternalcombustion(IC)enginepistonandthenhasused thestate-of-the-artANSYSfiniteelementanalysispackagetoperformalinearstaticanda coupled thermal-structural analysisof the component. Further, a parametric evaluationofthematerialpropertiesvis-à-visoperatingconditionsiscarriedouttogeneratearelational database for the piston to arriveat optimaldesignsolutionsunderdifferentoperatingconditions. Wanget al.(2010)has reportedasolidmodelincludingpistonandpistonpinofanewdesignedpistonbyPro/Esoftware, andthefiniteelementanalysismodelwasalsoestablishedby usingANSYSsoftware.Thethermo-mechanicalcouplingstressdistributionandthe deformationwerefirstlycalculated.Consideringthe nonlinear material properties ofpistonandpistonpin,theNewton-Raphson equilibriumiterativemethodis applied.Calculatingresultsindicatesthatthemaximumstressconcentrationis attheupper endofpistonpinbossinnerhole,andismainlycausedbythepeakpressureofthefuelgas.Zenget al.(2010)hassetupageometrymodelofadieselenginespistoninUGgraphics.Thetemperature fieldsofthepistonforburningdieselandDMEseparatelyarecalculatedusingANSYS10.0.The resultshowsthatthevariationofthethermalloadby substitutingdieselwithDMEis stillwithinthe thermalstrengthofthematerial.ThetemperatureoftheDMEfueleddieselenginedecreasesalong thepistonaxisfromtoptobottom.ThetemperatureofthepistonofDMEfueledengineincreaseas a wholecomparingwithburningdiesel.However,thetemperaturefielddistributionhas no significant changedecreasesandthenincreasesfromthecombustionchambercenterto theedge,anddecreases again tothe edge of the piston top. Durat. et al (2012) a steady-state thermal analysis was performedto evaluatethetemperaturegradientsinthestandardandtwodifferentpartiallystabilized ceramiccoatedpistonsbyusing Abaqus©finiteelement(FE)software.Asharpincreaseinthe temperature of the coated area of the piston was observed as a result of FE simulations. Itis concluded that the annulus Y-PSZ coating may contribute better, as compared to Mg-PSZ, to decreasethecoldstartandsteadystateHCemissionswithoutautoignition,sincethetemperaturein theareashowsalocalsharpincrease.Junjuetal.(2012)hastriedtoreducetheintensityofthermal andstructuralstressesbyusingtheceramicmaterialSiliconNitrideasthematerialforpistoncrown (thetopportionofthepiston).Asthecrownmaterialis brittleinnatureandskirtmaterialis ductilein nature.AceramicreinforcedfiberstripwasintroducedinbetweenceramiccrownandAlalloyskirt toavoidfailureoftheceramiccrownduetoitsbrittlenaturewhenitissubjectedtoimpactloadsthat areresultofexplosionof combustiongases.InthisworkEutecticAlAlloy(Si11-13%)wastakenas pistonmaterial.Initiallythermalandstructuralanalysiswasperformedon Al Alloypistonwithout siliconnitridecrownandthenwith siliconnitridecrownusingthesoftwareANSYS.Thentheresults obtainedarecompared. Thecomparisonofresultsindicatedthatthepistonwhichisarrangedby siliconnitridecrownisbettertowithstandhighthermalandstructuralstressesthanthepistonwhich isnot arrangedby siliconnitridecrown.Thepresentworkhasbeenundertakenwiththefollowing objective.

1- T o designanICengine(pistonandpistonring)byusingCATIAV5R20software

2- T o performthestructuralandthermalanalysis(ofpistonandpistonring)usingANSYS14.5 software.

Threedifferentmaterialshavebeenselectedforpistonandtwodifferentmaterialsforpistonrings.

1.1 Materials and their properties

1.1.1 For piston

	Ductile Nodular Spheroidal cast iron	ASTM grade 50 (ISO grade 350, EN – JL 1060) Grey cast iron
Poisson ratio	0.275	0.26
Modulus of elasticity (GPa)	176	157
Thermal conductivity (w/m k)	33	46
Ultimate tensile strength MPa	414 – 827	362
Yield tensile strength (MPa)	240 – 621	228
DENSITY g/c.c	7.2	7.1

For piston ring

	Al alloy 4032	AISI4340 Alloy Steel	Titanium Ti-6Al-4V
Poisson ratio	0.35	0.28	0.342
Modulus of elasticity(GPa)	79	210	113.8
Thermal conductivity (w/m k)	155	44.5	6.7
Ultimate tensile strength MPa	380	745	950
Yield tensile strength MPa	315	470	880
Density g/cc	2.68	7.8	4.43

.Dimensionsare calculatedandtheseareused formodelingthe pistonandpistonringin CATIAV5R20asshowninFig1andFig2.

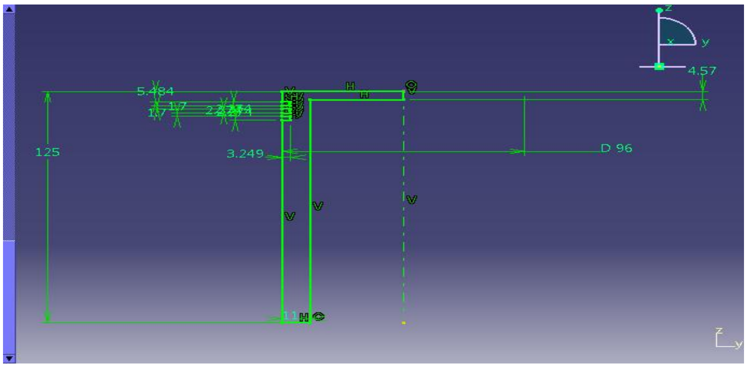


Fig.1 PistonDrawingandDimensions

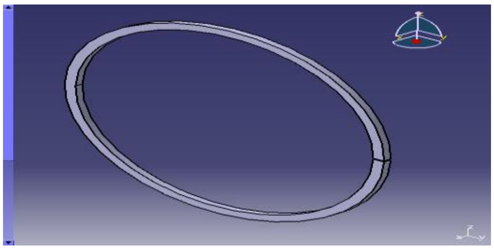


Fig.2 ThreeDpistonring

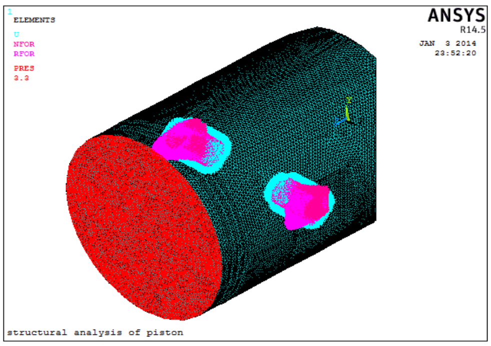
These were thenimported toANSYS 14.5forstructural andthermalanalysis. Structural analysisofpistonisperformedonANSYS14.5mechanicalAPDLandthermalanalysisisperformed onANSYS 14.5 workbench. Structural andthermal analysisofpistonringisperformed onthe ANSYS14.5workbench.

2. Boundary Conditions for Structural Analysis of Piston

Combustionofgasesinthecombustionchamberexertspressureontheheadofthepiston duringpowerstroke. Thepressureforcewillbetakenasboundaryconditioninstructuralanalysis usingANSYSmechanicalAPDL. Fixedsupporthasgivenatsurfaceof pinhole.Becausethepiston willmovefromTDCtoBDCwiththehelpoffixedsupportatpinhole.Sowhatevertheloadis applyingonpistonduetogasexplosionthatforcecausestofailureofpistonpin(inducingbendingstresses).Pressureacting onpiston=3.3N/mm^2asshowninFig.3.

3. Boundary Condition for Thermal Analysis of Piston

Thethermalboundaryconditionsconsistofapplyingaconvectionheattransfercoefficient andthebulktemperature,andtheyareappliedtothepistoncrown,landsides,pistonskirtshownin Fig.4. Maximumonpistonheadtemperature= 859.7^{0}C, Bulktemperature= 25^{0}C,Heattransfer coefficientonpistonsurface=3200W/m^2K,Maximumtemperatureat edgespiston=482.7^{0}C,Heat transfer coefficient on edge piston = 2400 W/m^2K, Heat transfer coefficient onlandsrings=1600W/m^2K,Heattransfercoefficientonpistonskirt=1000W/m^2K



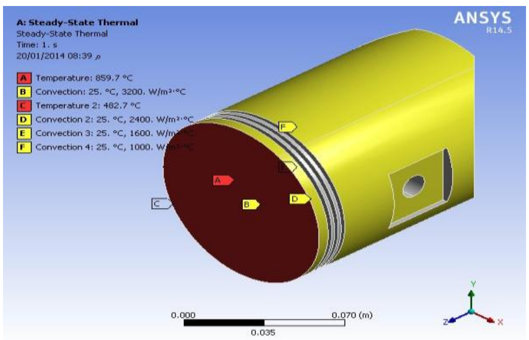
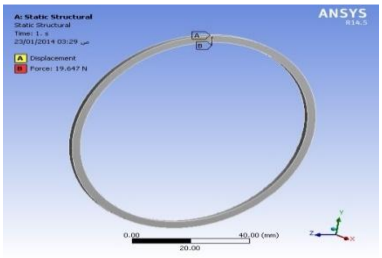


Fig.3boundaryconditionofstructuralanalysis **Fig.4**boundaryconditionforthermalanalysis

4. BoundaryConditionforStructuralandThermalAnalysisofPistonRing



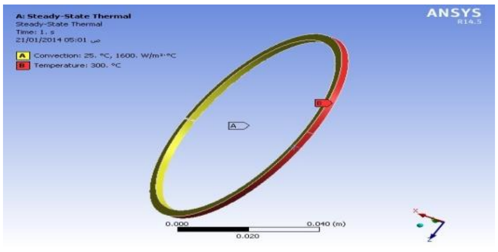
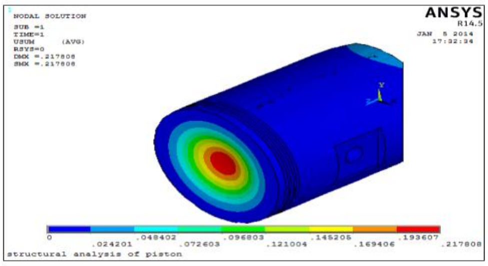


Fig.5boundaryconditionforstructuralanalysis **Fig.6**boundaryconditionforthermal



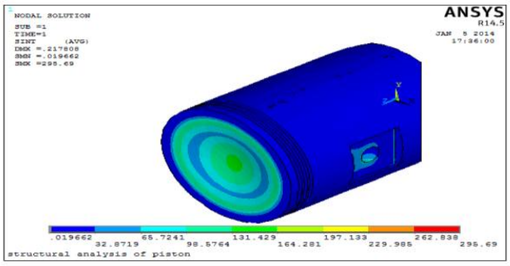
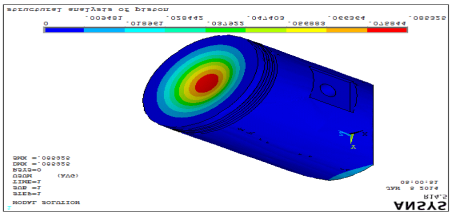


Fig.7 DisplacementvectorsumforAlAlloy4032 **Fig .8**StressintensityforAlAlloy4032



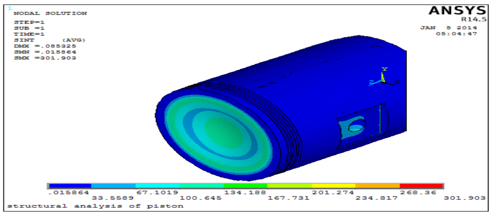
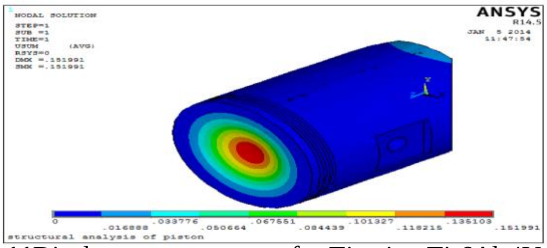


Fig.9 DisplacementvectorsumforAlloySteel4340 **Fig.10**StressintensityforAlloySteel4340



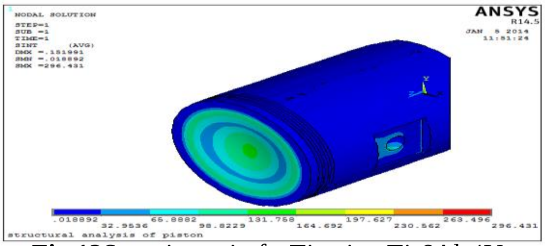


Fig.11 Displacementvectorsumfor TitaniumTi-6Al-4V **Fig.12**StressintensityforTitaniumTi-6Al-4V

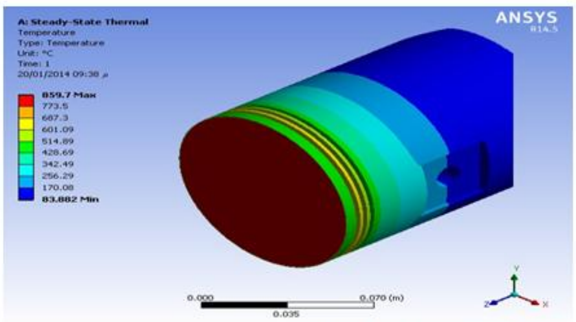


Fig.13 temperature for Al Alloy 4032

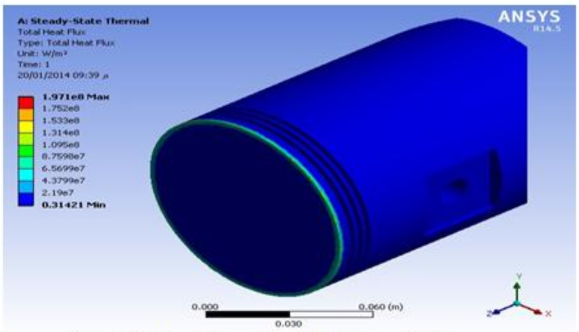


Fig.14 Heat flux for Al Alloy 4032

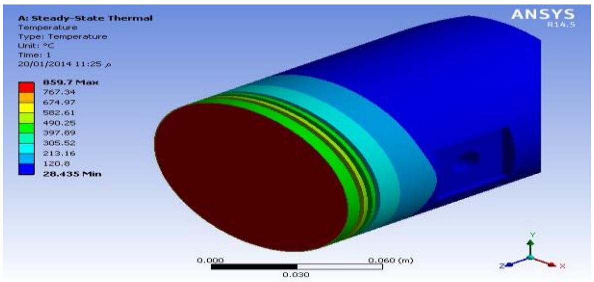


Fig.15temperatureforAISIAlloySteel4340

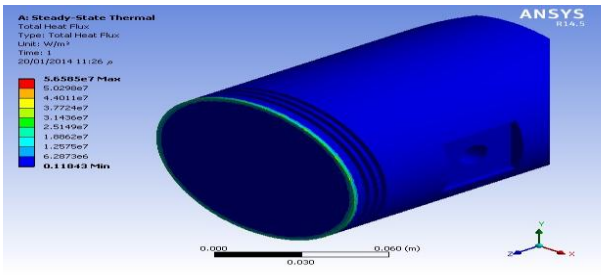


Fig.16 HeatfluxforAISIAlloySteel4340

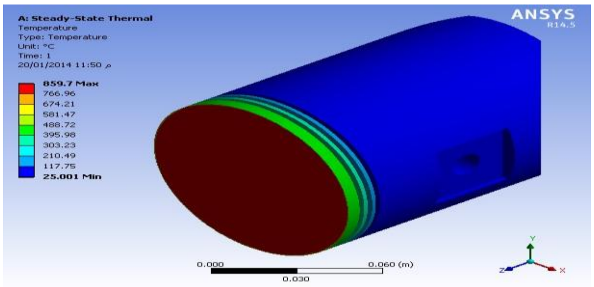


Fig.17temperatureforTitaniumTi-6Al-4V

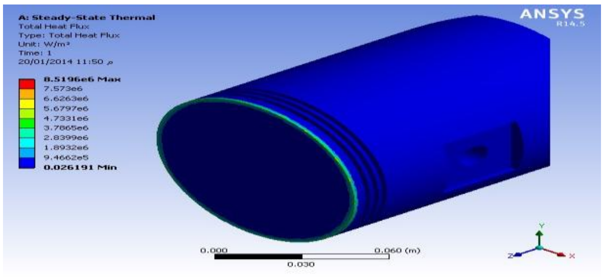


Fig.18 Heatfluxfor TitaniumTi-6Al-4V

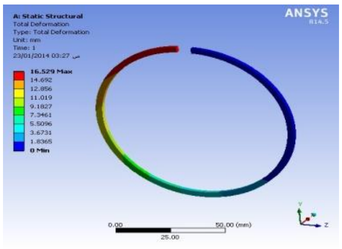


Fig.19 totaldeformationforNodular Spheroidal castiron

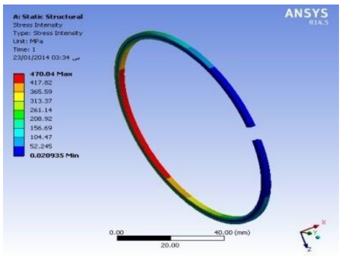


Fig.20 StressintensityforNodular Spheroidal castiron

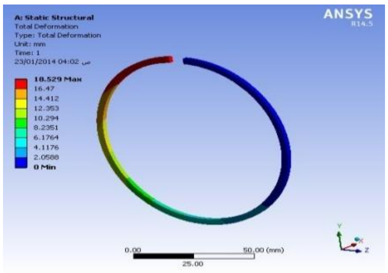


Fig.21totaldeformationforgreycastiron

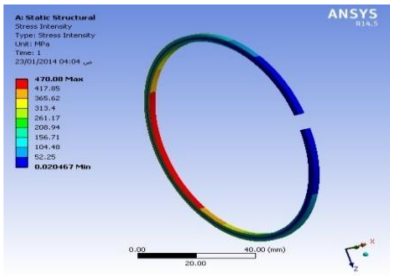


Fig.22 Stressintensityforgreycastiron

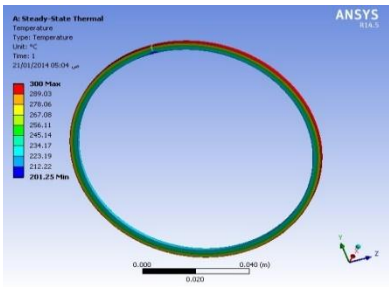


Fig.23 TemperatureforNodular Spheroidal castiron

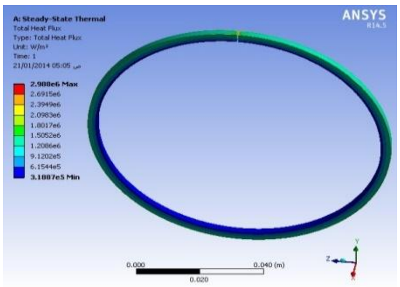


Fig.24 TotalheatfluxforNodular Spheroidal castiron

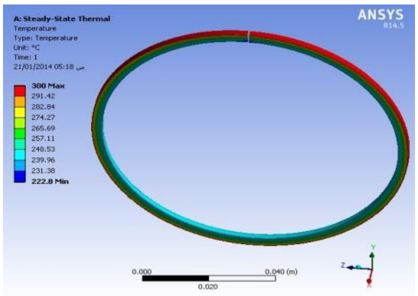


Fig.25 Temperature forgreycastiron

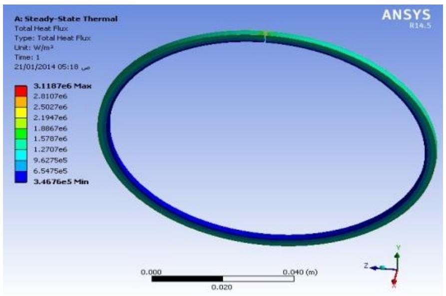


Fig.26 Totalheatfluxforgreycastiron

V. Results and discussion

Itisclearfromfigure7,9and11thatthemaximumdisplacementisobservedinthepiston made of Al alloy 4032 and minimum in AlSl 4340 alloy steel. As itis expected maximumdisplacementisobservedatthetopofthecentreofthepiston.Itisshowninthefigure8,10&12 thatthemaximumstressintensityisobservedinAlSl4340with301.903MPaandminimumin Alalloy4032with295.69MPa.Itis observedthatthe maximumstressintensityisonthebottom surfaceof theallpistoncrownandalongtheedges.Againin pistonmadeoftitaniumalloymoderate stressintensityisfound.WhereastheyieldstrengthofthepistonisveryhighinTitaniumalloy pistonfollowedbyAISI4340steelandAlalloy4032. Thermalanalysisofpistonshowsthatthevalueofmaximumtemperatureis sameforallthe materialsatthetopsurfaceofthepistoncrown,butminimumvalueoftemperatureinthepiston madeoftitaniumalloy.Thehighestvalueof minimumtemperatureis foundinthepistonofAlalloy. Thisisduetothermalconductivity ofthematerials. Minimum temperatureisintheskirtofthe pistonisobservedasshowninfigure13,15&17. Figure14,16&18showsthatmaxtotalheatfluxisobservedinpistonofAlalloyandpiston oftitaniumalloyshowsthelowestvalueofmaxtotalheatfluxalongtheedges. PistonringsaremadeofNodularSpheroidalCastIron&GreyCastIron.GCIPistonRings showmoredeformationthaninNSCI.Stressintensityisequalinboth.Maximumtemperature isequalinbothmaterials, whereminimum temperatureishigherinGCI,whichis222.8^{O}C. Here, MaximumtotalheatfluxisobservedinGCIpistonrings&minimumvalueinNSCIpistonrings.

VI. Conclusion

Itisconcludedfromthe abovestudythatusingCATIAV5R20softwaredesignandmodeling become easier. Only few stepsareneededtomake drawinginthree dimensions. Same canbe importedtoANSYSforanalysis.PistonmadeofthreedifferentmaterialsAlalloy4032,AISI4340. AlloysteelandTitaniumTi-6Al-4V(Grade5) areanalyzed.Theirstructuralanalysisshowsthatthe maximumstressintensityisonthebottomsurfaceofthepistoncrownin all the materials,butstress intensityisclosetotheyieldstrengthofAlalloypiston.Maximumtemperatureisfoundatthecenter ofthetopsurfaceofthepistoncrown.Thisisequalforallmaterials. Dependingonthethermal conductivityofthematerials,heattransferrateisfoundmaximuminAlalloypistonandminimumin Tialloypiston.Forthegivenloadingconditions,Alalloypistonisfoundmostsuitable.Butwhen theloadingpatternchanges,othermaterialsmaybe considered.Withtheadvancementinmaterial science,verylightweightmaterialswithgoodthermalandmechanicalpropertiescanbe usedfor fail safedesignoftheI.C.engine.Thiswillreducethefuelconsumptionandprotecttheenvironment.

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